A Multi-Channel Interface Circuit with Low Substrate Noise for Surface Acoustic Wave Sensor Array

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ABSTRACT

Electronic nose (E-Nose) is one of the applications for surface acoustic wave (SAW) sensors. In general, the SAW sensor, as a gas sensor, consists of a passive element (LiNbO3 and IDTs) and an oscillator circuit, as shown in Fig. 1. For the E-Nose applications, a SAW sensor array is formed to construct the odor patterns for gas recognition. Because the oscillator frequency of each sensor is so close that the injection current through the substrate seriously affect the performance of the phase noise of the SAW sensors [1]. If the number of the SAW sensors increases, more injection current would raise the output noise level of the SAW sensors, as shown in Fig. 2. The noise will affect the sensitivity of the SAW sensor because the frequency change from the SAW sensor is very small at sensing low concentration gas. In the previous works [2] [3] [4], asynchronous types SAW sensor array system have been developed to implement a portable E-Nose to reduce the interference between sensors. However, the data acquired from the asynchronous type SAW sensor array system is not continuous, thus it is not suitable for further analysis. In contrast, synchronous type SAW sensor array system has the advantage of data integrity. In this paper, we focus on the design of low substrate noise synchronous type SAW sensor array system. We used deep N-Well to separate the substrates of NMOS transistors to reduce the injection noise from the substrates between sensors. Likewise, the power and the ground of the sensors were also separated. The system was implemented by an application-specific integrated circuit (ASIC) that converted the analog sensor signal into digital. The proposed circuit has been fabricated by TSMC 0.18µm 1P6M CMOS process technology. The chip operated at 1V supply voltage for digital circuits and 1.8V for analog circuits, respectively.

ARCHITECTURE

The SAW sensor oscillator consists of a CMOS cross coupled pair and a passive element. The cross coupled pair offers negative resistance to the passive element for the oscillator to oscillate continuously. Eq. (1) below shows the relationship between phase noise and jitter, where J represents jitter (f_s); f_m is the frequency offset from the center frequency; f_o is the center frequency; $(N_o/P_o)_{fm}$ is the phase noise magnitude at f_m (dbc/Hz)[5].

$$J^2 = 2\frac{f_m^2}{f_o^3}\left(\frac{N_o}{p_o}\right)_{f_m} \tag{1}$$

To estimate the limitation for low concentration gas measurement, the phase noise can be calculated from Eq. (1). For jitter lower than 1.5fs, the phase noise should be lower than 178dbc/Hz@1MHz. The SAW interface ASIC is composed of a mixer, a low pass filter, a multiplexer, a time-to-digital circuit, and a mod 10^5 circuit, as shown in Fig. 3. To eliminate temperature and humidity effects, a reference SAW sensor without film coating is used. The mixer and the low pass filter together obtain the frequency difference between the polymer-coated SAW sensor and the reference sensor. For data analysis, Eq. (2) below is used to normalize the frequency difference, where $f\text{-}f_{ref}$ is the output of the low pass filter.

$$f_{\text{normalize}} = \frac{f - f_{ref}}{f_{ref}} \tag{2}$$

The mod 10^5 circuit acquires the center frequency of the reference SAW sensor. In this work, we used four SAW sensors in the sensor array, including the reference sensor. An analog multiplexer switch the output signal from the low pass filters. Finally, the time-to-digital circuit converts the analog signal into digital.

CONCLUSION

The oscillator center frequency of the SAW sensor was 115MHz, and the phase noise was -180dbc/Hz@1MHz. The time domain jitter was 1.12fs. With 1.8V supply voltage, the output amplitude of the oscillator was 900mVpp, and the power consumption was 8.56mW. The substrate interference noise was -5db lower than that without using deep N-well separation. The input range of the time-to-digital circuit was 0.5MHz~3.8Hz, and the power consumption was lower than 1mW under 1V supply voltage. Table.1 shows the benchmark comparison with other related works.

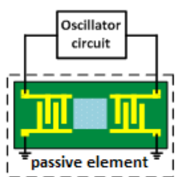

Figure. 1 SAW Sensor

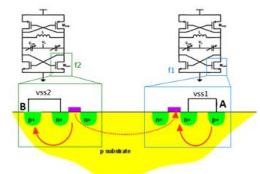

Figure. 2 Injection Current Through Substrate

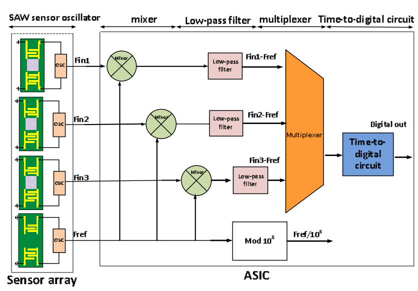

Figure. 3 System Block Diagram.

	[2]	[3]	[4]	This work
CMOS process	0.35um	0.18um	0.35um	0.18um
Supply voltage	3.3V	1.8	3.3V	1.8V/1V
Die area	0.85mm^2	1.987mm^2	1.5mm^2	1.448mm^2
power	38.35m	4.92mW	-	366.49u
Frequency range	300M~400M	300M~350M	259.3M	113M~116M
Output type	voltage	voltage	Analog signal	Digital code
Channel numbers	2	2	2	4

Table. 1 Benchmark

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